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Procedure for experiential learning to conduct material flow simulation projects, enabled by learning factories

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Abstract

Material flow simulation is a powerful tool to identify improvements in factory operation. For conducting simulation projects, experts are required who know how to prepare, execute and evaluate simulation studies. To date, training mostly focusses on textual case studies, whereby learners perform simulation studies based on a problem and data given in a description. However, this hardly reflects the ways engineers learn. They are mostly used to physically experiment based on their experience. In this paper, a procedure for experiential learning to conduct material flow simulation projects is elaborated, enabled by learning factories. A learning situation at Vietnamese-German University is described. Results indicate, that the students gain particular awareness about the challenges associated with the abstraction of the reality and the interpretation of the simulation outcomes.

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Keywords: simulation; learning; learning factory; experience

1. Introduction

Production planners are facing trade-offs in factory planning and operation. They need to find a good balance between targets like the minimization of the throughput time, due date deviation, inventory and the maximization of the capacity utilization, in order to maximize the profitability [1]. Discrete-event simulations (DES) can provide a basis for coping with this complex challenge. A simulation is the representation of a system with its dynamic processes in an experimentable model [1]. A model is an abstracted representation of the reality [1]. Abstraction is the process of reducing complexity of a problem through separating details of problems into relevant and non-relevant, resulting

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in a limited representation of the system [2]. In DES a model evolves over time by a representation in which state variables change instantaneously at separate points in time, so-called events [3].

In order to execute a simulation project, experts are required. They need to have technical competencies in factory planning and operation, and need to be trained in the preparation, execution and evaluation of simulation projects.

2. Education in Simulation

The German working group on simulation (ASIM) distinguishes between "education in simulation" (EDU in SIM) and "simulation in education" (SIM in EDU) [4]. EDU in SIM aims at the education in modelling and simulation, whereas SIM in EDU focusses on simulation for education in the sense of e-learning and blended learning. In this paper, mainly the EDU in SIM perspective in the sense of conducting projects with material flow simulation is addressed.

2.1. Conducting a simulation study

A simulation study mainly consists of a preparation, an execution and evaluation phase. During the initial phase, the problem and the goal of investigation are specified and data are collected. In the second phase, an initial model has to be created, validated and verified. Verification is the process of inspection of the syntax and execution of tests to ensure the correctness of the simulation model [1]. Validation means the examination of the sufficient correspondence between model and original [1]. Experiments are conducted according to an experiment plan. Finally, data are analyzed, interpreted and conclusions are transferred to reality. [1, 3, 5]

Kühn introduced in 2006 the so-called simulation cycle, showing the principle steps of a simulation project in an easily comprehensible manner [5]. It is shown in Fig. 1, detailed according to [1] and [6]. Kühn specifies that the simulation cycle is to be passed, until a satisfactory result is achieved.

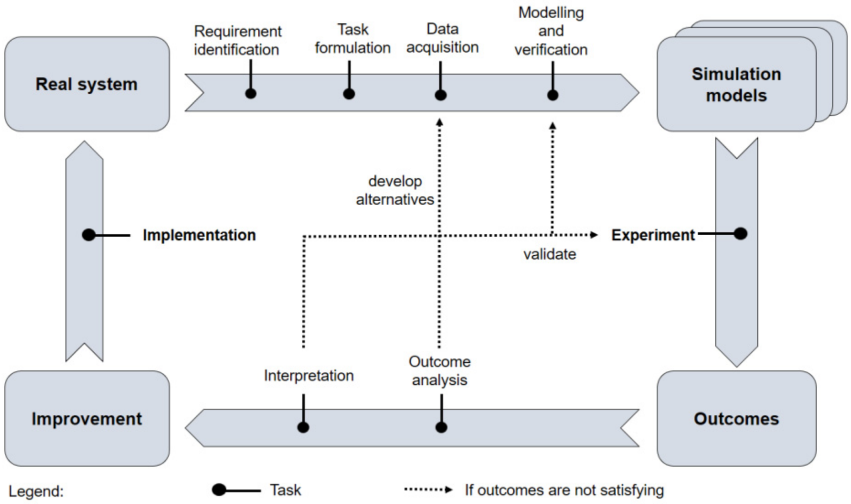

Fig. 1. Simulation cycle according to [1, 5, 6]. It shows the generic procedure of conducting a simulation project, beginning with the "real system".

2.2. Experiential learning

One widely acknowledged model of a learning/problem-solving process has been formulated by the psychologist Kolb in 1971. Today this is known as the experiential learning cycle, which is shown in Fig. 2. Concrete experience is followed by reflective observation, which leads to the formation of abstract concepts and generalization, leading to hypotheses' to be tested in future action, which in turn leads to new experiences. Kolb highlights that this learning cycle is continuously recurring. In this sense, learning is considered as re-learning. Since the learning process is directed by individual needs and goals, learning styles become highly individual. E.g. abstract conceptualization might be more interesting for mathematicians than for engineers. [7]

Since engineers mostly are building up upon experiences they gained before, an approach of experiential learning interpreted for conducting material flow simulation projects seems to be promising.

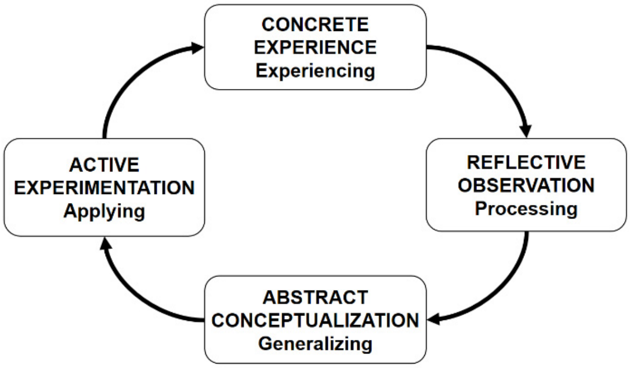

Fig. 2. Experiential learning cycle according to [7].

2.3. Learning factories

Learning factories pursue an action-oriented approach with participants acquiring competences through structured self-learning processes in a production-technological learning environment. Learning factories thereby integrate different teaching methods with the objective of moving the teaching-learning processes closer to real industrial problems [8]. Learning factories can consist of a physical and/or virtual learning environment, need to have a didactical concept and should emphasize experimental and problem-based learning. To date, the CIRP Collaborative Working Group on learning factories collects and analyzes various definitions and strives towards the joint establishment of a common understanding of the term learning factory [9].

Learning factories seem highly suited to support the experiential learning process, because learners can perform problem solving hands-on in the sense of Kolb's cycle.

2.4. Qualification for material flow simulation

Frantzén and Ng, 2015, report about a teaching course with industrial students who are working on practical oriented simulation studies [10]. Students are solving a problem of the individual company during the course. Prerequisite therefore is firstly, that an industrial case is available that fits with respect to the scope into the course and secondly, that the lecturer's capacity for mostly time-consuming supervision of individual projects are available. Learning factories provide wonderful chances of coping with this challenge. In the literature, approaches relating learning factories and material flow simulation education are hardly documented. In the sense of SIM in EDU, examples are available like Scholz et al. 2016, who report about the integration of intralogistics into resource efficiency oriented learning factories [11]. They use a so-called pre-programmed simulation environment to show people differences in the resource consumption between two delivery concepts in their learning factory. Prinz et al. 2016 briefly describe the usage of material flow simulations for manufacturing control in a learning factory [12]. In the context of Industry 4.0 learners shall realize, that if they use simulation for so-called manufacturing control aspects, there is no need for manual manufacturing control. Approaches linking learning factories and material flow simulation in the sense of EDU in SIM could not be identified.

To date, education for material flow simulation mainly bases on textual case studies, e.g. [13]. Hypothetic cases are described as a basis for learners to build up simulation models, perform experiments and interpret outcomes. Learners can hardly train to choose the appropriate degree of abstraction, because in most cases all relevant data with respect to the goal of investigation are available. Taking assumptions is mostly not necessary. Additionally, effects caused by poor validation of the simulation model can hardly be demonstrated to the learners.

Education for conducting material flow simulation projects needs to be improved to avoid wrong decisions to be taken by unexperienced production planners, in particular when they conduct a simulation project for the first time in industry. A procedure for experiential learning for conducting material flow simulation projects is introduced. It is designed to be applied in a learning factory. A learning situation, using the learning factory of the Vietnamese-German University (VGU) is described, and the feedback of students is evaluated. Exemplarily, special emphasis is placed on the minimization of due date deviation.

3. Procedure for experiential learning to conduct material flow simulation projects

The procedure consists of Kühn's simulation cycle in the center, surrounded by Kolb's experiential learning cycle, see Fig. 3. It shows the procedure of experiential learning to conduct material flow simulation projects. The procedure is to be applied with a learning factory. In this sense, the **real system,** shown in Kühn's simulation cycle of Fig. 3, is to be interpreted as a learning factory. **Simulation models** are abstracted digital representations of the learning factory's information and material flows, including resources. **Outcomes** refer to the results of the simulation experiments. **Improvements** are outcomes, interpreted by the user with respect to the applicability in reference to the learning factory.

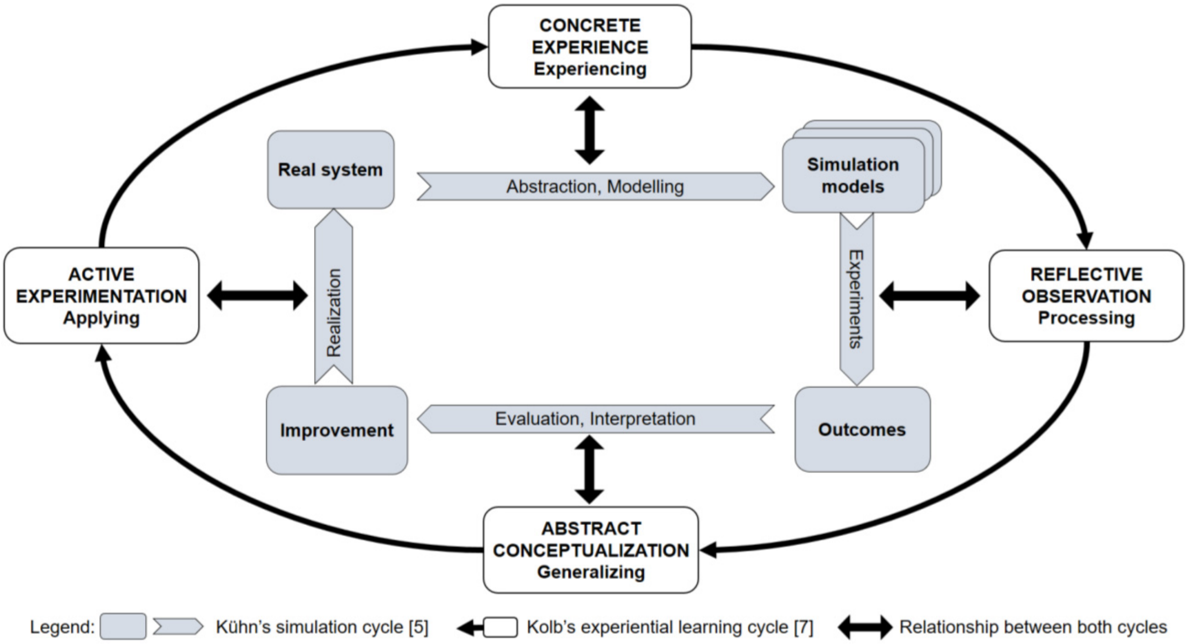

Fig. 3. Procedure for experiential learning to conduct material flow simulation projects.

During the **modelling** phase, the user has the **concrete experience** of building up a simulation model. This includes the specification of the problem and goal of investigation, data collection and the build-up of the initial digital simulation model. In order to find and eliminate a bottleneck, the user mostly performs sensitivity analysis. In a sensitivity analysis, only one variable is changed while all others stay the same [2]. While performing such an analysis, the user needs to **reflectively observe** the output-parameters of the experiments with respect to the goal of investigation. This observation helps the user to build up an understanding of the system behavior. After reaching a satisfactory simulation outcome, the results need to be **interpreted and evaluated** with respect to an application in reality. Since the outcomes are based on the simulation model, which is only an abstracted representation of the learning factory, the **abstract conceptualization** is trained through mentally transferring the outcomes reached with simulation to reality. After the improvement has been specified, it can be **implemented** into reality. Therefore e.g. stations of the learning factory can be rearranged or the personal allocation be changed. The **active experimentation** relates to both, the implementation of the improvement into the learning factory and the operation of the learning factory with the implemented improvement.

The main benefit is letting learners experience a simulation project. They need to gather data of the learning factory they operate, build a digital simulation model, perform simulation experiments, evaluate the results and finally implement their improvements into the learning factory they operate then again. Learners experience, whether e.g. their assumptions taken during modelling, the degree of abstraction and the validation have been appropriate, latest when they operate the factory they "improved" before.

4. Case study at Vietnamese-German University (VGU)

A course on material flow simulation with students of the VGU in Ho-Chi-Minh City, Vietnam, took place in summer 2016. One major part of this course was dedicated to mediate how simulation projects are conducted. The procedure described in section 3 was applied. In the following subsections the learning situation and infrastructure available at this University is documented and student's feedback is analyzed.

4.1. Infrastructure and learning situation

On seven workstations (OP), five different types of so-called trolleys are assembled by students. The initial layout of the workstations as well as the product variants are shown in Fig. 4. At station 1 the students select a frame and place all wheel-holders on it. At stations 2 to 5 one wheel is assembled each at one wheel-holder. At station 6 the finished trolley gets a label and is packed at station 7 into a box. This division of work leads to a tact time of about one minute and thus a throughput time of seven minutes when five students are assembling in the learning factory. [14] [15]

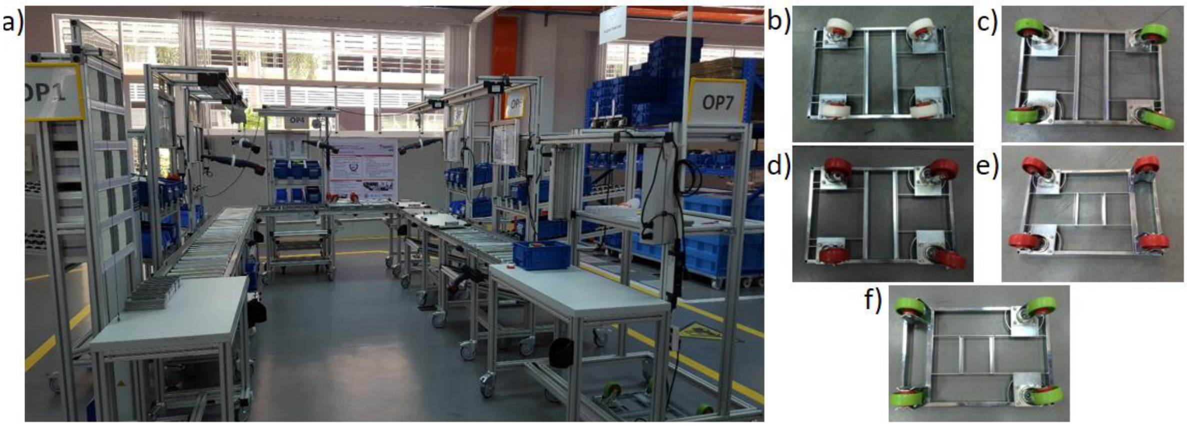

Fig. 4. (a) U-layout of learning factory showing seven workstations; (b)-(f) shows the five variants of the final products, so-called trolleys: (b) 4 swivelling wheels, white; (c) 4 swivelling wheels, green; (d) 4 swivelling wheels, red; (e) 2 fixed and 2 swivelling wheels, red; (f) 2 fixed and 2 swivelling wheels, green.

In order to create a challenging simulation task, the following assumptions have been taken.

- The customer takes a packed trolley from the final storage every minute. The product type is randomly selected according to a normal distribution with the average value $\mu = 2$, variance $\sigma^2 = 3$, with a lower bound = 1 and an upper bound = 5. Students do not know this random distribution. Initially a final stock of one to two trolleys of every variant is available. There is no upper limit of final products to be stored.

- If the customer demand is not fulfilled, a lost sale is assumed. A postponement of orders is not possible. For every successful product sold, 5€ of earnings are assumed.
- The customer directly returns the trolley after unpacking to the learning factory. Since the number of frames circulating in this closed-loop system is limited to overall 20 and the customer demand exceeds this limit, it is required to disassemble trolleys.
- The maximum number of employees allowed to operate the factory is five.
- The production is to be started with work in progress.

In order to maximize the profitability, students necessarily need to focus on ideas towards the minimization of due date deviations. Since the trolley is assumed to be a mass product available also at competitors, a lost sale is assumed for every not fulfilled order, having a negative effect on the profitability. Students need to take decisions that influence the availability of packed trolleys in the final storage. Examples are:

- Students need to decide whether to prioritize the assembly or disassembly. Decision variables are the current stock of finished products and the frames available for assembly. Disassembly is necessary due to a closed loop system with a limited number of frames.
- Students need to decide which type of trolley to assemble or disassemble. Decision variables are the stock of returned finished products and the current stock of finished products.
- Students need to decide how to divide the work tasks.
- Students need to decide how many products of every variant they store in the final storage.
- Students need to decide whether to place storages for semi-finished products into the factory.

On the basis of those exemplarily mentioned decisions to be taken, students needed to develop a set of rules for production control in order to compete against the other groups of students with respect to the profitability.

4.2. Course of the exercise with students

With about 30 students allotted to five groups, the learning unit for conducting material flow simulation projects took about five full days. It was conducted as the final activity of a teaching course on material flow simulation. At the beginning of the activity, the students knew relevant theory of how to conduct a simulation study. All learners mainly studied during the first two weeks of the course how to use the software Tecnomatix Plant Simulation on the basis of textual case studies. Thus, students knew about how to apply the software and the functionalities available. In one of the student's previous courses all participants gathered experience in assembling trolleys in the learning factory according to lean principles.

One the first day of the learning unit for conducting material flow simulation projects, randomly selected students were asked to run the learning factory for 45 minutes. All the other students were requested to gather relevant data. They measured e.g. the duration of the single work steps, observed the distribution of work between the test persons incl. their waiting times, and made notes about the decisions taken, like whether to assemble or disassemble. Students also observed the behavior of the customer, taking one packed trolley every minute from the final store.

The customer's demand could only be satisfied – as expected - in 21 of 45 cases. This relates to an order-fulfillment rate of about 47%. With the goal of making the factory more profitable, the student's task was to improve the course of action in the factory, leading to decreasing due-date deviations.

On days two and three, students were not allowed to operate the factory for performing physical experiments with it. This is considered as a valid assumption, because even in a real production environment hardly substantial changes for experiments can be made due to safety and security reasons. Thus students were required to perform their experiments with a digital model. Therefore, they abstracted the reality they observed before and built up a "current" validated and verified simulation model. Based on this model, students performed their experiments, according to an experiment plan, every group defined individually.

On the fourth day, for every group of students one hour was reserved in the learning factory, split into two parts. During the first 30 minutes, the students have had time to rearrange the workplaces and tools according to their suggested improvements. Also, the students were required in this period of time to reset the learning factory into an initial state with work in progress. The next 30 minutes were determined for producing trolleys in the individually improved learning factory. However, to avoid effects of extraordinary speed of assembly due to a high motivation, another group of students was supposed to assemble in the learning factory, guided by the original group of students. The original group of students measured again the relevant data like throughput or due-date deviations and observed the events in reality during the 30 minutes of assembly and disassembly. Typical improvements of students comprise e.g. additional buffers for intermediate products to decrease the replenishment time, see Fig. 5 for an example.

For the last day, the students presented their work in class. Specifically, they have been asked to point out differences that might have been existed between the improvements they determined via simulation and the observations they made while the improved learning factory was operated.

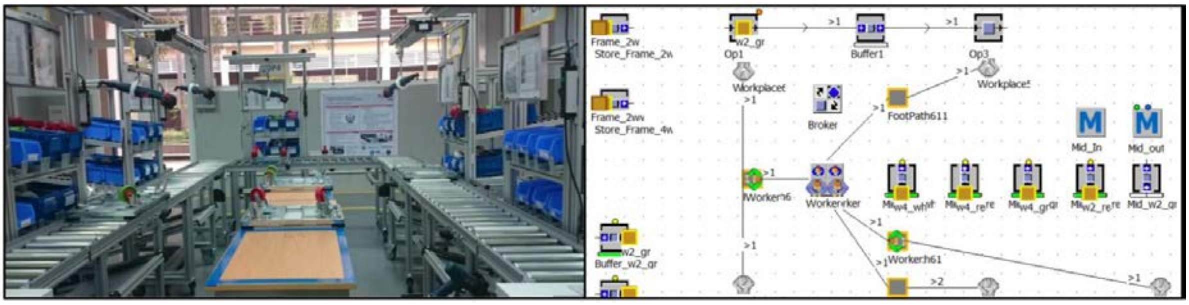

Fig. 5. Picture of one of student's improvements including a buffer for semi-finished products (left) and screenshot of corresponding simulation model (right). Students showed, that they were able to faster react on customer demands.

4.3. Student’s feedback

It is written in the final reports of the students, that all groups performed more than one simulation experiment in order to overcome the bottleneck. The bottleneck was named in all cases to be the high workload of workers / the low number of workers allowed to assemble and disassemble in the learning factory. All groups of students decided to change the work allocation. In most of the cases, they included additional buffers for semi-finished products into the learning factory, in order to be able to react faster to customer orders, see Fig. 5.

Except of one group, all documented being not able to satisfy the customer demand according to the expected results, gained with their simulation scenarios. Four groups of students draw this back to workers making mistakes or being slower than expected. Additionally, one group reported on an insufficient communication with the workers, and another mentioned empty batteries of tools. All students stated not being satisfied with their results after the learning factory exercise. Without being asked to perform further experiments, all groups documented to have performed further simulations.

4.4. Interpretation of Student’s feedback

It is notable that four out of five groups of students did not reach their target value of fulfilled customer orders in the learning factory compared to the digital simulation. This result indicates, that the students took wrong or too generic assumptions during the modelling phase with respect to the relevant parameters that influence the system behavior (abstraction): E.g. workers mistake rate = 0%, no communication problems and tool availability = 100%. The effects of those assumptions got visible during the active experimentation and realization phase in the learning factory. This learning effect could have hardly been generated with a textual case study.

The efforts of students creating voluntarily more improvement scenarios after the course indicates firstly their high motivation and secondly the need to re-design the exercise. The procedure for experiential learning to conduct material flow simulation projects should be run through more than one time in order to iteratively learn from previous simulation and implementation experiences.

5. Summary

Material flow simulation is a powerful tool to support production planners in taking decisions with respect to the profitability of factories. Simulation supports the user in building up an understanding of the system behavior and in developing alternatives in a safe and secure digital environment. Prerequisites to exploit those benefits are, that people have technical competencies in factory planning and operation, and are trained in the preparation, execution and evaluation of simulation projects. To date, the application of simulation is subject to specialists, specifically trained to conduct simulation projects. Mostly, written case studies are used to educate those specialists. However, choosing the appropriate degree of abstraction and taking assumptions can hardly be trained with such case studies. To contribute to increasing the learning productivity, a procedure for experiential learning for conducting material flow simulation projects has been developed. The simulation cycle has been harmonized with the experiential learning cycle. The procedure has been applied in a course with students. The simulation cycle describes the workflow of a simulation project. The experiential learning cycle shows how people are learning, based on their experiences. An exemplary test as final project in a course with students took place in the learning factory of the Vietnamese-German University. Particular emphasis was placed on increasing the profitability of a trolley production with special focus on minimizing due date deviations. Therefore, students changed the layout and work allocation in the learning factory based on improvements they determined with a digital simulation model. However, most groups of students could not satisfy the customer orders in the learning factory as expected. Results of the test indicate that the students realized that they abstracted the processes taking place in the learning factory too extensive when they built up their simulation models. Compared to traditional textual case studies, the students became aware about the effects of inadequate abstraction of the reality and the interpretation of simulation outcomes. In other words, they experienced that a thorough preparation, execution and evaluation of simulation studies is prerequisite for determining a good balance of targets in production systems. Future research will address a mobile learning environment for the simulation-supported design of value creation networks.

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